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AMERICA'S FIRST LONG-RANGE-MISSILE AND SPACE EXPLORATION PROGRAM: THE ORDCIT PROJECT OF THE JET PROPULSION LABORATORY, 1943-1946: A MEMOIR+

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I. INTRODUCTION

The years covered by this memoir, contrasted to those discussed in my first two memoirs,[1,2] were extremely hectic. It is very difficult for me even now to draw anything like a clear and coherent picture of them. Nevertheless, by drawing attention to unpublished material available in the archives of the Jet Propulsion Laboratory, I hope what I have to say will be of use to historians of astronautics.

Between 1943 and 1947 I became increasingly involved as an administrator of research. The Air Corps Jet Propulsion Research Project, GALCIT,[2] which numbered around 85 persons in 1943, grew to around 400 by 1946, and the amount of money to worry about increased from hundreds of thousands to millions of dollars annually. Although directly acquainted with all that was taking place on the Project up to 1944, both as regards ideas and their execution, by 1946 I was aware of more and more research activities but in less and less detail, and little of my time was free for carrying out research of my own—a situation unpleasing to one of my temperament.

Theodore von Kármán's connection with the California Institute of Technology (Caltech) became increasingly tenuous in 1942, and in 1944 he became absorbed with activities in Washington, D.C.,[3] where he took up residence. Consequently, in 1944 I took over contract negotiation from both technical and management points of view, tasks that required frequent trips to Wright Field at Dayton, Ohio, to Washington, D.C., and to other places. Life became a "between trips" kind of existence.

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By 1944 it was fairly evident that World War II would end in the defeat of the forces of fascism in Germany, Italy and Japan. But what then? In 1945 the harnessing of atomic energy for destructive purposes was demonstrated at Alamogordo, New Mexico, and then at Hiroshima and Nagasaki, Japan. As I was drawn into the councils of those with military responsibilities, I participated more and more in discussions of what should be done in the next war with long-range rocket missiles. Obviously, if atom bombs could be made light enough, they could be used as missile warheads. Such deliberations became more and more distasteful to me as the months went by. I had long been convinced that war between or by states with advanced technology was a form of national insanity, even before a way to release nuclear energy had been found. It seemed to me that ideas and effort were really needed now to find ways for "sovereign" states to function in peace together, rather than to develop better means of destroying themselves.

By 1946 I was mentally and physically exhausted. General Eisenhower is said to have remarked when the war ended that all he wanted to do was to go fishing; I felt the same way, except that I do not care very much for fishing. I had completed 10 years of rocket research, and dealt with problems on the fringes of basic and engineering science knowledge, devices requiring the use of explosives and toxic chemicals, the safety of our staff and of aircraft test pilots, frustrations resulting from dealing with administrators who had no grasp of the nature of research, travel by train and by air to meetings that frequently were not really necessary, etc. Thus, at the age of 34, I determined to make a serious appraisal of myself and of my hopes for the future.

When we had begun rocket research at Caltech in 1936, most of our original group of six was dedicated to the peaceful uses of rocket propulsion.[1] The design of a sounding rocket had been our first goal. Though I never lost sight of our first goal, world developments by 1938 dictated our participation in the military application of rocket propulsion. When the WAC Corporal became the first successful sounding rocket to exceed heights attainable by any other means in 1945, I felt a sense of personal fulfillment. I understood that this was but the first probe into extraterrestrial space, and that voyages to the Moon and planets would follow, but I also knew that there were now many others who would carry on the work necessary to reach these more distant goals. In 1936, the number of engineers in the world seriously interested in astronautics was probably less than 50; by 1946 there were several hundreds.

What troubled me most about leaving JPL was the separation from the members of the staff, many of whom were my closest friends and with whom I had shared many good and many trying times. I have never again worked with a group that was as cooperative and enthusiastic. But the new goal that I had set for myself was international cooperation. Although I left Caltech with a two-year leave of absence, which was renewed in 1949, I then allowed it to lapse and, in one way or another, devoted myself to international cooperation during the past 25 years. The night before I departed from Texas for Unesco in

Paris, one last effort was made to dissuade me from leaving the Jet Propulsion Laboratory (JPL). A general officer of the Ordnance Department telephoned me from Washington, D.C., and urged me to reconsider my decision. When I asked von Kármán for his advice he had told me that if he were younger, he would follow a path similar to the one I had chosen; it was unlikely that anyone else would get me to change my mind.

I made a tour of the East Coast to discuss Unesco with many persons before going to Paris. Albert Einstein thought that major points of the Unesco program were definitely worthwhile. He said we must have courage to fight for real issues and not allow Unesco to become impotent, like the Commission for International Intellectual Cooperation of the League of Nations. Vannevar Bush said that scientists must work together to stop wars for good. He did not know very much about Unesco but supported it. Lyndon B. Johnson, then the Congressman from the district of my home in Texas, said he was not acquainted with Unesco intentions and that the United Nations was just a "baby."

Upon my arrival in Paris, Joseph Needham, Head of the Natural Science Section of Unesco, assigned me the task of studying ways to break down the barriers to the free movement of scientists and engineers between nations. It certainly was not true that I became a member of the Unesco secretariat as a rocket expert, as was stated in an article hostile to the organization in the Saturday Evening Post entitled "Julian Huxley's Zoo." Unesco did not come within a smell of rockets before the International Geophysical Year (IGY) in 1957.

While at Unesco, outside my official duties, I wrote a popular article entitled "Unmanned Rockets towards Space" in 1950, upon the invitation of Kenneth W. Gatland, who served as the editor of a collection of articles for a book called Rockets into Space. But that venture was given up by the publisher in 1954. In 1950, I also wrote "A Short History of Rocket Propulsion up to 1945" for the Princeton University series of volumes on Jet Propulsion and High Speed Aerodynamics of which, at that time, my long-time colleague, Martin Summerfield was editor. That article was finally published in the volume Jet Propulsion Engines in 1959.[4]

I did not resume work in astronautics until after the launching of the Sputnik by the Soviet Union in 1957, an event that made more evident than ever the need for international cooperation in this field. Andrew G. Haley, one of the founders with us of the Aerojet-General Corporation[2] and then President of the International Astronautical Federation, and von Kármán, who had become active in Federation affairs, told me that it was all very well to work quietly as an artist in a Paris studio (which I had been doing since 1953 after leaving Unesco) but that my experience in astronautics was wasted. They urged me to participate in the work of the Federation.[3] After much discussion with my wife, I decided to accept appointment as a representative of the Federation to Unesco. By 1959, I was again devoting most of my time to astronautics in the Federation, especially in connection with the establishment and direction of the International Academy of Astronautics.

But to return to the subject of this memoir . . . .

II. THE SITUATION ... 1943

The Air Corps Project at the beginning of 1943 was consolidating the successfull development of solid-and storable-liquid-propellant engines for aircraft superperformance applications with research directed to improving the propellants, raising engine performance, and increasing their thrust and duration. Cooperation on matters of development and production was maintained with the Aerojet Engineering Corporation for those programs sponsored by the Air Corps and the Navy.[2] The Project had placed solid-and storable-liquid-propellant rocket engine design on a sound scientific foundation. Practical information had been provided engineers, permitting the design of uncooled motors to meet specifications for thrusts of up to around two tons for durations of up to about 75 seconds. By the end of World War II, information on the design of cooled liquid-propellant engines and of pumps was well advanced.

Albert A. Christman, in his history of the Naval Weapons Center entitled Sailors, Scientists and Rockets, observed: "A suggestion by a Navy captain that it would be desirable to have a cooperative effort between Goddard and Malina brought out Goddard's view that the work in Pasadena was about the stage in 1940 that his work had been in 1925. He referred to the Caltech program as the 'Student Work.'"[5] Goddard evidently did not subscribe to von Kármán's maxim: "It is always wise to remember that someone else might be just as clever as oneself." Goddard's opinion of our efforts does not surprise me,[1] but he must have been surprised when, within two years after his remarks we had successfully developed and put into production for the Air Forces and the Navy service-type solid-and storable-liquid-propellant engines. These became, respectively, the progenitors of the engines in, for example, the Sergeant, Polaris, and Minuteman missiles, and the Tital missile and the Apollo Command Module and Apollo Lunar Excursion Module.

This raises an interesting question concerning developments in Britain, USA and USSR after the end of the war, a question that should be probed by historians of rocketry and astronautics. I believe a good case can be made to show that military obsession in these countries for continuing certain developments of German rocket technology caused a vast waste of funds. The obsession gave priority to rocket engines using liquid oxygen (LOX), as in the case of the V-2. In the U.S.A., though the development of engines using a composite solid-propellant and a storable-liquid-propellant combination was not dropped, it certainly was assigned a lower priority. But today, not a single American military operational missile uses a LOX engine, instead they are propelled by descendants of solid- and liquid-propellant engines developed at JPL before the end of World War II.

The investment in LOX engines turned out to be an overall technological gain, for they were indeed needed for extraterrestrial space activities, but they were not then and are not now of primary interest to the military services. What is more, solid and storable liquid propellants also have an important role to play in the propulsion of spacecraft at this phase of the "space age." Nonetheless, popular opinion, even the opinion of some who should know better, has held that rocket developments in the U.S.A. lagged far behind that of Nazi Germany. That belief is patently false, but myths die hard.

III. ORIGINS OF THE ORDCIT PROJECT

At the Air Corps Project in 1943 we continued to follow the directives of 1939 that limited us to rocket engines for use with aircraft.[2] In the Summer of 1943 this situation changed radically. In early July, von Kármán received a request from the Commanding General of the AAF Materiel Center, Wright Field. He was asked to study and comment on three British Intelligence reports on reaction propulsion devices for projectiles and aircraft supposedly being developed in Germany.[6,7,8] Von Kármán's comments, based on an investigation that he, Hsueh-Shen Tsien (Chien Hsueh-Sen) and I made, were sent to Wright Field on August 2. Although much of the data from German prisoners in the reports was incorrect, inexact, and exaggerated, it was possible to draw some interesting conclusions. The fact that our conclusions bore little resemblance to actual German missile and aircraft developments, as we learned later, is irrelevant to their impact on the 1943 military scene in the U.S.A. Fascinating background material on these intelligence reports, to be read with circumspection, can be found in the book The Mare's Nest by David Irving.[9]

The AAF Liaison Officer at Caltech at this time was Col. W. H. Joiner, a most congenial and helpful officer. He immediately appreciated the significance of our conclusions and suggested to me that a study should be made of the possibility of propelling ballistic missiles with the rocket engines we had developed or that were available at Aerojet. I turned to Tsien for help, and the two of us completed our study in November.[10] The results showed that although ranges in excess of 100 miles could not be reached with available engines, rocket missiles could be constructed that had a greater range and a much larger explosive load than rocket projectiles then being used by the Armed Forces. After discussing the analysis with us, von Kármán decided to attach a memorandum to our report proposing that a development program be initiated along the lines we had indicated.[11] These documents for the first time carried the name "Jet Propulsion Laboratory." Joiner sent the memorandum and analysis to the Commanding General at the AAF Material Center. Captain R. B. Staver, an Army Ordnance Liaison Officer at Caltech, occupied an office next door to Joiner. Staver also forwarded these same documents to Colonel G. W. Trichel, Chief of Rocket Development Branch of the Army Ordnance Department.[2]

Von Kármán, Tsien and I at this point concentrated our thoughts on the technical problems of long-range missiles and on what appeared to us to be the most reasonable steps to be taken to develop them on the basis of current experience in the U.S.A. with solid and liquid propellant rocket engines. Staver and Joiner, on the other hand, pursued quite a different thought process. Staver later told me that they were concerned with assuring continued support of the development of rocket and other types of jet engines and of their application by the military services after World War II. They feared the historic tendency of the government to drop potentially important research for military purposes when a war ended. Furthermore, they believed that our Project should not only be continued, but expanded to become a center of jet propulsion and missile research and development.[13] I have pointed out before that there was a conflict of opinion as to the kind of work that could or should be undertaken by an academic institution of higher education and research.[2] Von Kármán and I were of the view that Caltech was an appropriate organization to take responsibility for basic engineering research, but not for the development of prototypes of engines and of vehicles that involved problems of meeting production and end-result specifications. The fact that the ORDCIT Project did include these latter activities can be understood only in terms of the special situation prevailing in the U.S.A. in 1944.

The response of the military services to the two documents on the development of long-range missiles planted a seed for the bitter inter-service military rivalry that took place in the 1950s. I recall discussions with officers in the Air Forces and the Ordnance Department on the appropriate "botanical" classification of a rocket missile. Those concerned with army ordnance said that, since long-range guided missiles followed a ballistic trajectory like a gun projectile, such missiles were clearly a responsibility of the Ordnance Department. Those responsible for long-range aircraft bombers said that, since a long-range guided missile needed aerodynamic control during the first phase of flight in the atmosphere, the Air Forces clearly should be responsible for their development, and they called the missiles "pilotless aircraft."

But the Air Forces did not respond to our proposal, much to our amazement. Instead, von Kármán received a letter on January 15, 1944, from Trichel of Army Ordnance. It expressed not only interest in the proposed program, but a desire that Caltech undertake a more intensive program than originally outlined.[12] Trichel urged that a revised and more inclusive program be undertaken at the earliest possible date. He further stipulated that the Ordnance Department was prepared to furnish the necessary funds to cover such a project providing Caltech, in turn, was willing to give the necessary emphasis to the undertaking in the assignment of personnel and facilities. He also recommended that a proposal be submitted that would include a chronological schedule of the studies to be made, models built, etc.; further, if such a project was decided upon, it would be advisable to make a contract with Caltech on a cost-plus-a-fixed-fee basis. The plan of operations should initially cover not more than one year and the expenditures should not exceed $3,000,000 for the one-year program.

Trichel's letter threw us into a proper dither! We prepared a new proposal incorporating his suggestions, and von Kármán, with the support of Robert A. Millikan, Chairman of Caltech's Executive Council, obtained the approval of the Caltech Trustees to put forward the proposal to the Ordnance Department. On January 20, Brig. General B. W. Chidlaw, Chief, Material Division Office, Assistant Chief of Air Staff, directed a letter to the Commanding General of Materiel Command, Wright Field, requesting the following information:[12]

a) Will the Army Air Forces authorize the use of the facilities at GALCIT by the Ordnance Department?

b) Will such a long-range development contemplated by the Ordnance Department conflict with work being conducted by the Army Air Forces?

Von Kármán also responded on February 1 to Major General Frank O. Carroll, Chief Engineering Division, AAF Materiel Command, Wright Field, inquiring about AAF interest in research directed towards the development of aircraft or pilotless-aircraft traveling at transonic speed, and apparently helped the Materiel Command formulate answers to the above questions.[12,14] Accordingly, on February 17 the AAF Material Command at Wright Field cleared the Ordnance project to proceed at GALCIT, so far as the AAF was concerned. Also, Carroll sent a letter to von Kármán approving, under his supervision, a project for "athodyd" (ramjet) engine development with the Ordnance Department that could be used on aircraft, provided AAF research would not be retarded in any way.[12]

Events now moved rapidly. On February 28, 1944, von Kármán submitted on behalf of Caltech a new proposal, based upon Trichel's suggestions, to Major General G. M. Barnes, Chief of the Technical Division, Ordnance Department, in Washington, D.C. This proposal was accepted practically intact[12] (It appears in the appendix). A Letter of Intent for the Army Ordnance program was placed with Caltech on June 22 "for services consisting of research, investigation and engineering in connection with the development of long-range rocket missile and launching equipment and for complete reports, drawings and specifications describing all work done in connection therewith." An expenditure not exceeding $1,600,000 was authorized. A definitive contract followed, and entered into force on January 16, 1945, with the following objectives:[12]

a) The missile would have a minimum weight of high-explosure payload of 1000 pounds.

b) Maximum weight of the missile would not exceed a weight consistent with good design and maximum payload.

c) The missile would have a range of up to 150 miles.

d) Target dispersion at maximum range would not exceed 2 percent for a missile suitable for direction by remote control.

e) The velocity would be sufficient to afford protection from fighter aircraft.

The termination date of this contract was set at December 22, 1954; however, it was later extended through June 30, 1946; the total funds provided amounted to $3,600,000.

This expanded program led to a reorganization of the Air Corps Jet Propulsion Research Project, GALCIT, into the Jet Propulsion Laboratory, GALCIT. The new program was given the designation ORDCIT Project (ORDCIT is an acronym for Ordnance-California Institute of Technology).

IV. REORGANIZATION OF THE AIR CORPS PROJECT INTO THE JET PROPULSION LABORATORY

The ORDCIT Project required rapid expansion of the staff and facilities of the Jet Propulsion Laboratory (GALCIT), or, JPL. During the period under consideration, JPL was attached to the Guggenheim Aeronautical Laboratory (GALCIT) directed by von Kármán. He remained titular director of GALCIT until 1949, when he became Professor Emeritus and Clark B. Millikan succeeded him. By this time, JPL had been separated from GALCIT and came directly under the overall administration of Caltech.

While we were in the midst of preparing plans for carrying out the program of the ORDCIT Project, von Kármán underwent serious abdominal surgery at the end of May 1944, in New York City, which prevented him from returning to Pasadena until September. While he was recuperating in New York, General H. H. Arnold, Commanding General of the AAF, asked him to undertake the creation of the Scientific Advisory Board to the Chief of Staff of the AAF "to investigate all possibilities and desirabilities for postwar and future war's development as respects the AAF." Von Kármán left for Washington, D.C., in December 1944, thereafter returning to Caltech only for short period of time.

The scope of the ORDCIT Project posed Caltech administrators with novel problems. How would they manage the range of activities, the size of the JPL staff, and the amount of money involved? They decided to establish a JPL Executive Board, responsible to the Caltech administration, whose task would be to oversee the general policies of JPL administration and the implications of any new technical developments that took place. Then, when von Kármán took leave of Caltech, the question of who would direct JPL had to be resolved. C. B. Millikan was asked to become Chairman of the JPL Executive Board, and I took over as Acting Director at JPL. But the implications of this division of responsibilities soon required clarification.

From my long experience of working with von Kármán, I knew that a certain coolness existed between him and C. B. Millikan; to be sure, I had inherited this feeling.

I also could not easily forget that, if von Kármán had not overruled him, Millikan would have stopped the GALCIT Rocket Research Group in the spring of 1936. When Millikan stated in the autumn of 1944 that he expected as Chairman of the JPL Executive Board to chair regular weekly JPL project conferences, I exploded. I told him that I could not continue making technical and administrative decisions if the conferences were run by someone who was not intimately aware of what was going on in the laboratory from day to day. Von Kármán supported me.

Neither my relations with the JPL Executive Board, nor those of Louis G. Dunn, who succeeded me as JPL Director in 1947, were ever very satisfactory. On one occasion in 1945 I became so irritated with Millikan when he presented a summary of work underway to the Board, that I slammed down my papers, announced my resignation, and stalked out of the meeting. The next day, after taking into account the reasons for my displeasure, Millikan and other Board members convinced me to change my mind. But the problem of divided responsibility was never resolved. Dunn, when he became JPL Director after I left, simply refused to attend meetings of the JPL Executive Board, and Caltech finally dissolved the Board in 1948.

In 1944, Col. L. A. Skinner was designated Liaison Officer for the Army Ordnance Department. Those of us concerned with solid propellant rocket engines were acquainted with his studies in the 1930s of nitroglycerine-nitrocellulose as a propellant. I also had met him when he worked with the "Indian Head Group" at Indian Head, Maryland, in the early 1940s.[5] Joiner was succeeded by Col. E. H. Eddy as Liaison Officer for the AAF, and Lt. Col. J. W. Newman was designated Liaison Officer by the Army Ground Forces.

Beginning in 1944, research at JPL was carried out on four major projects: JPL-1 (Project MX 121 of the Aircraft Laboratory of the AAF Materiel Command, was a continuation of the program previously carried out for the Aircraft Laboratory[2]); JPL-2 (Project MX 363 of the Armament Laboratory of the AAF Materiel Command, begun in 1943,[2] was on hydrobomb research); JPL-3 (Project MX 527 of the Power Plant Laboratory of the AAF Materiel Command, begun in 1944, was primarily on ramjet engine research[2]); and JPL-4 (the ORDCIT Project).

The ORDCIT Project involved not only fundamental engineering research on thermal jet propulsion engines, propellants, and the design of guided missiles, but also the construction of missiles and launching devices for firing tests. The firing tests were to be made in cooperation with the Ordnance Department. Thus, we had to become accustomed to thinking in terms of design and construction of much larger devices and equipment than before. We were greatly helped in meeting this situation by Romeo R. Martel, Caltech Professor of Civil Engineering and a member of the JPL Executive Board, and by Aladar Hollander of the Byron Jackson Co., of Los Angeles, a manufacturer of pumps. The design of large constructions required to develop and launch missiles was guided by William A. Sandberg of the Consolidated Steel Co. of Los Angeles. Mark Serrurier of Caltech supervised the design of installations for ramjet engine studies. Eugene M. Pierce, Sr., an architect who had been my personal assistant since 1943, and W. Hertenstein, head of maintenance and buildings at Caltech, bore the brunt of designing and contracting for new buildings that had to be constructed as quickly as possible. The construction program was further aided by the Ordnance Liaison Officers--Skinner up to August 1945 and thereafter, Colonel Benjamin S. Mesick. Val C. Larsen took charge of Laboratory administration in 1946, and supervised material procurement. William R. Stott, Assistant Comptroller at Caltech and I spent many days on contract negotiation. The layout of buildings and special facilities of JPL in June 1945 is shown in Figure 1.

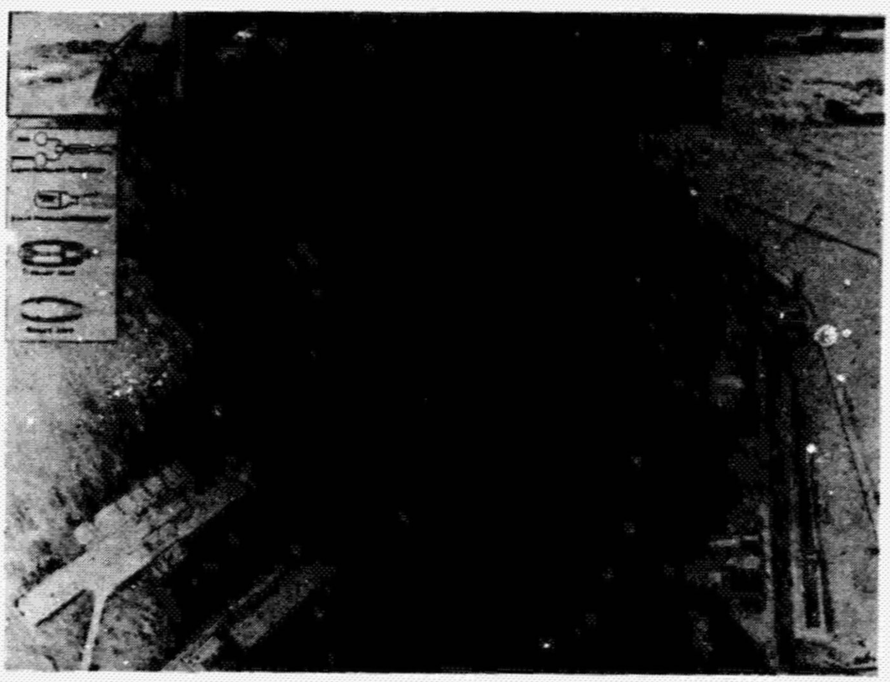

Fig. 1
Layout of the Jet Propulsion
Laboratory, June 1944

The organization chart of JPL as of January 9, 1945, is shown in Figure 2. The Technical Section Chiefs were:

H. J. Stewart, Section 1, Research Analysis
J. V. Charyk, Section 2, Underwater Propulsion
H. S. Seifert, Section 3, Liquid Propellant Rocket Engines
C. Bartley, Section 4, Solid Propellant Rocket Engines
P. Duwez, Section 5, Materials
S. A. Johnson, Section 6, Propellants
W. B. Barry, Section 7, Engineering Design
J. Amneus, Section 8, Research Design

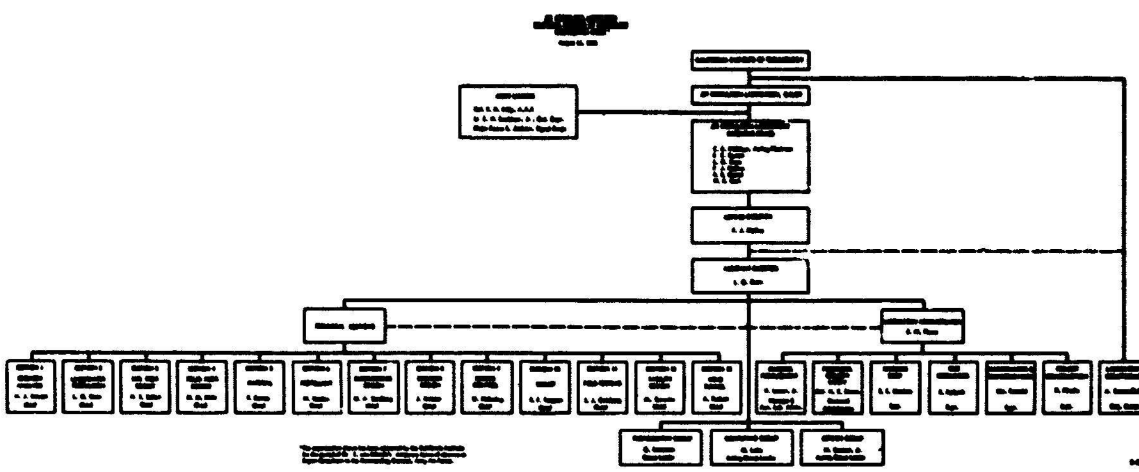

Fig. 2
Organization Chart of the Jet Propulsion Laboratory, 14 August 1945

W. H. Pickering, Section 9, Remote Control

W. D. Rannie, Section 10, Ramjet Engines

S. J. Goldberg, Section 11, Field Testing

Tsien, who had been the first chief of the Research Analysis Section, left Caltech for the Massachusetts Institute of Technology in 1946. He returned in 1948 to set up the Jet Propulsion Center established at Caltech by the Daniel and Florence Guggenheim Foundation. Martin Summerfield returned to JPL from the Aerojet Engineering Corporation in the autumn of 1945 to take part in planning and research analysis of possible applications of rocket propulsion to extraterrestrial space flight.

I have already discussed from my viewpoint the high points of research undertaken on solid-and liquid-propellant rocket engines and on ramjet engines up to the end of 1946 at JPL in my memoir on the Air Corps Jet Propulsion Research Project.[2] I shall discuss briefly below the research on guidance and control of missiles that William H. Pickering, a later Director of JPL, initiated in 1944.

V. 1944 MISSION TO EUROPE

Colonel F. F. Reed, called "Froggy" by his friends, visited JPL in the summer of 1944. He was Assistant Military Attache, Ordnance Department, in London. We decided that I should return his visit by going to Great Britain to study rocket and ramjet engineering research, to obtain firsthand experience in the target area of the V-1's and V-2's, and to inspect the parts of the V-2 that had strayed off course and landed in Sweden. I went to Washington at the beginning of September for a briefing and to obtain orders for my visit from the European Theater of Operations (ETO). After some delay, a return trip to Pasadena,[16] the orders appeared. During the first week of October I flew to Prestwick, Scotland, and then took the train to London. Since my trip included an inspection of German V-1 launching sites and other kinds of installations in northern France (Pas de Calais region) liberated in August, I was given the rank of Colonel (assimilated rank, in case of capture), with the instruction that I was not to wear an insignia on my uniform. Considering that I had received the rank of 1st Lieutenant in the Officer Reserve in 1942, which I had to resign in order to continue rocket research at Caltech, I considered the jump in rank pretty good.

Upon the urging of Reed, I designed and had a tailor make a shoulder patch with a rocket on it--perhaps the first U.S. military insignia signifying rocket missiles (Figure 3). Although 32 years old, I looked much younger, and on my return journey, when I checked in at Bolling Field in Washington, D.C. to catch a B-17 to Los Angeles, the sergeant at the desk looked at my identity card, then looked at me and said, "Don't kid me, you can't be a Colonel!"

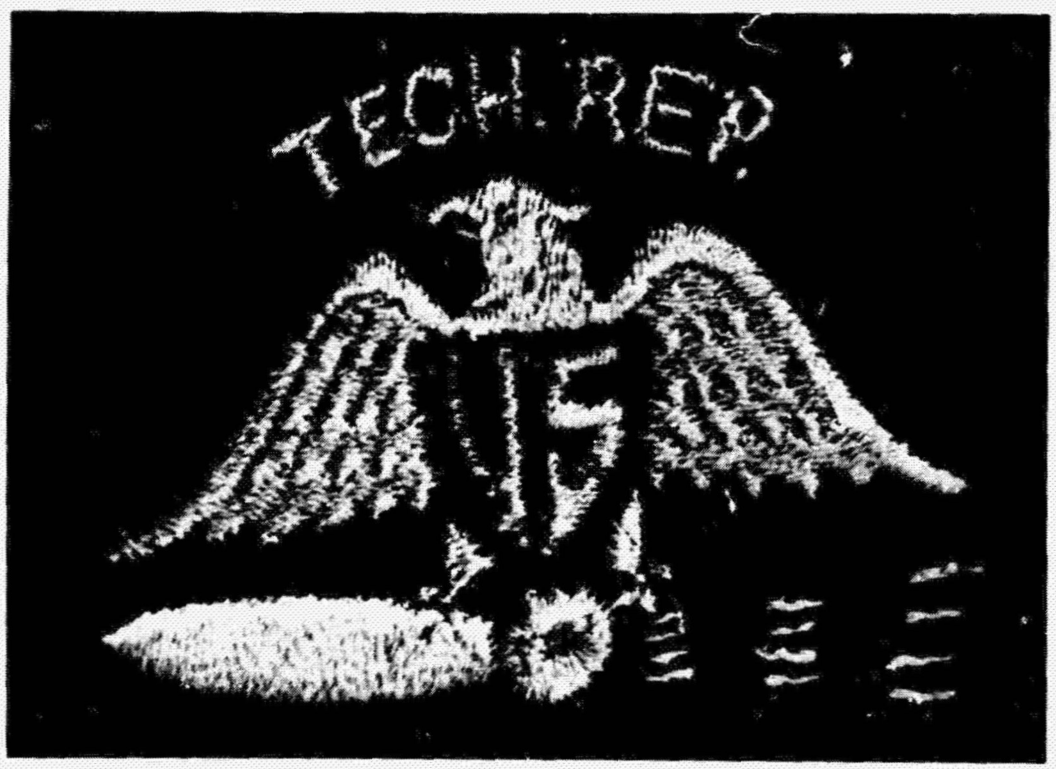

Fig. 3
Unofficial Rocket Missile Shoulder Patch Designed and Worn
By the Author in the European Theater of Operations, 1944

Eighty-two names of engineers and scientists in the United Kingdom appear on the list of those with whom I discussed various aspects of my mission, among them: Sir Alwyn D. Crow, Controller of Projectile Development, London; W. Blackman, Chief Superintendent, Projectile Development Center, Abeporth, Wales; J. E. Lennard-Jones, Chief Superintendent, Armament Research Department, Fort Halstead; Capt. A. Richards, Superintendent of Torpedo Exp. and Div. Greenock, Scotland; Commodore F. Whittle, Power Jets Ltd., Whetstone.

The discussions were quite open on both sides, although I knew that some information was held back, just as I held back on some of our plans and developments. Compared to research practice in the U.S.A., I was particularly impressed by the extent of British theoretical analysis and the length of debate on pros and cons before a decision was made to build something. This difference in approach was in large part due to the much more limited financial and manpower resources available in wartime Britain. I realize that our Private F fiasco, to be described below, might well have been avoided if a more thorough theoretical analysis of an unguided winged missile had been made.

The main interest in Britain in 1944 centered on the improvement, under the dominating personality of Sir Alwyn Crow, of an anti-aircraft rocket missile. Under his leadership, unguided anti-aircraft ballistite UP rockets (UP for unrotated Projectile) were developed and used in the Battle of Britain in 1941. Some said that the UP's should have been called "misguided" missiles, for, as Charles C. Lauritsen, who watched them perform in London that year is quoted to have said: "I don't think they ever shot down a bomber...."(5, p. 108) They did make a lot of noise, which perhaps gave a psychological boost to the people.

By the time I arrived in London in October 1944, only a few V-1's were still arriving during the night, launched from aircraft over the North Sea because land launching sites on the other side of the English Channel had been captured by the Allies. V-2's bombarded London from bases off the coast of Holland. One shook-up a conference I was attending at Fort Holstead. My first experience of this sort left me rather disturbed, but my colleagues continued the meeting as though nothing had happened.

Information was available on the V-2 and on German engines using LOX and hydrogen peroxide (H_2O_2). The British were of the view that the nitric acid-aniline propellant combination was less suitable than hydrogen peroxide and, hopefully, nitromethane. We at JPL did not go overboard on either of these latter chemicals as the British did. (By 1944, we had good reasons to doubt the great expectations of John W. Parsons and Fritz Zwicky for nitromethane as a monopropellant. It was tested extensively both at JPL and at Aerojet and, as far as I know, nitromethane was finally given up as a rocket propellant because it is sensitive to shock and is difficult to use as a rocket motor coolant.) Test facilities for liquid-propellant engines were still in a very primitive state in Britain, and work was just getting underway on composite solid-propellant engines of long-burning duration.

There was much interest in the possibilities of the ramjet engine, mainly because of German claims, especially by Eugen Sänger. The British knew considerably more than we did at JPL about the problems that needed to be solved to make a ramjet a practical device.[2] Ramjet studies were being carried out in England at Power Jets, Ltd., under Lloyd and Constant. Here, also, Air Commodore Frank Whittle was continuing his development of turbojet engines, and he and I compared experiences on the vicissitudes of those who try to get unorthodox ideas accepted.

I inspected the parts of the V-2 brought from Sweden to the Royal Aircraft Establishment at Farnborough early in 1944. Design elements of the engine and the guidance system were still not completely understood. The latter was especially of interest to us at JPL, since we now confronted the problems of missile guidance and control.

Between November 16-26, 1944, I visited France with Captain C. E. Martinson, who had been assigned by Reed to look after me during my mission. Our flight across the English Channel in a Douglas Dakota (DC-3) aircraft provoked me to say that we should not have crossed so quickly to Paris. We landed in a mist at the end of the afternoon and got out of the aircraft. When a pilot appeared, we asked for our transport to Paris. He exclaimed: "Paris? The mailbag had Brussels on it so that's where you are!" (The following significant facts were uncovered by the superstitious to account for our plight: we were on flight No. 13, the Dakota's number added up to 13, and there were 13 passengers!) Once in France, we inspected V-1 launching sites at Wizerne, Montreuil and Sivacourt. Strategic bombing by Allied aircraft had produced only minor damage to the rocket sites, whereas nearby villages were a shambles. At Mimoyecques and Watten were very large constructions whose purpose up to that time no experts could make out.

Martinson and I celebrated Thanksgiving Day with American officers in Paris. After a turkey dinner at the Hotel Plaza Athenee, we were taken in hand by a group of bomb disposal officers who had five gallon bottles of something called "desert juice"—really, I think, a mixture of cognac and cointreau, which would have been better used as a rocket propellant. On the flight back to London the next morning, H. P. (Robie) Robertson of Caltech, who was with the O.S.R.D. Mission in London, poured coffee into me to combat its effects.

While crossing the Atlantic on my return journey during the second week of December, the many hours gave me a chance to think over the implications of all I observed on my tour. When I had departed from JPL in October, plans were far advanced for testing the first ORDCIT solid propellant missile, Private A, for the design of a winged version, the Private F, and for the liquid propellant Corporal. Turning over the many bits of information stored in my mind, I suddenly realized that the first objective our rocket research group had set for itself in 1936 was within reach—a sounding rocket.[17-19] We now had reliable solid- and liquid-propellant engines with which to build it. But first I had to sell the idea to the Ordnance Department.

Before proceeding on to Pasadena, I visited Trichel and his staff during a stop-over in Washington, D.C. After reporting on my European mission, I presented my wish to have JPL design, construct and test a sounding rocket. I explained that the program could be carried out rapidly if modest requirements were set (to lift a 25-lb. payload to 100,000 ft). I also pointed out that a rocket with a liquid-propellant engine could be considered as a small-scale test version of the Corporal, experience would be gained with launching techniques, and the rocket might be considered a first step in the development of a guided anti-aircraft missile. The proposal was immediately received favorably. The Army Signal Corps established requirements for the rocket that met its meteorological payload needs.[2] By January 16, 1945, a study of the proposed sounding rocket, requested by the Ordnance Department, was completed by Stewart and me[20] (See Section VIII).

VI. THE PRIVATE A

The first missile to be tested used a solid-propellant rocket engine that could be quickly provided, as proposed by Tsien and the author in 1943.[10] It was called Private A, with the intention to name subsequent missiles in hierarchical order of army ranks. The JPL missile series ended in 1954 with the Sergeant, a solid-propellant surface-to-surface missile with an inertial guidance system. The Private A (also designated as the XF 10S1000-A) was designed to provide experimental data on the effect of sustained rocket thrust on a missile stabilized with fixed fins and on the use of booster rockets for missile launching.[21] A photograph of the missile is shown in Figure 4. It had a length of 92 in., a maximum diameter of 10.25 in. and 4 tail fins extending 12 in. from the body. The gross weight was 500-550 lb., including a payload of 60 lb. The solid-propellant motor, manufactured by the Aerojet Engineering Corp. (now Aerojet General Corp.) delivered a thrust of 1,000 lb. for about 30 sec. The specific impulse of the asphalt-base castable propellant GALCIT 61C was 186 sec.

The Private's launcher was a 36-ft.-long rectangular steel boom of the truss type, with four guide rails inside the truss. It was mounted on a steel base and both the lateral and vertical angles could be varied (Figure 5). The missile was boosted by 4 modified Ordnance Department aircraft armament rockets in a cluster as shown in Figure 6. The 4 rockets delivered a thrust of 22,000 lb. for 0.18 sec. They completed their burning and disconnected from the missile before it left the launcher. Full details on the design of the Private A, its booster and launcher, can be found in References 22 to 24.

Firing tests were made in the Mojave Desert at Leach Spring, Camp Irwin, near Barstow, California, between December 1-16, 1944, while I was in England. Twenty-four rounds were fired with an average range of approximately 18,000 yards; the maximum range was 20,000 yards (11.3 miles). The missile reached an estimated peak height of 14,500 ft. and an estimated maximum speed of 1,300 ft./sec. A view of the smoke trail of a

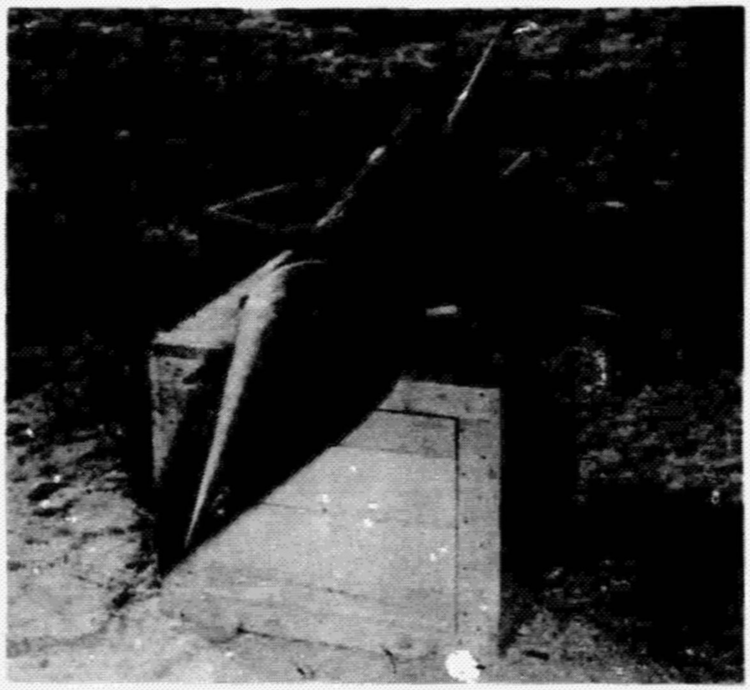

Fig. 4
View of the PRIVATE A Missile

Private A in flight is shown in Figure 7. Trajectory analyses were carried out by W. Z. Chien and C. C. Lin.[25,26] The firing tests were completely successful, meeting all of the objectives specified for the program. The Private A became the precursor of composite propellant rocket engine missiles the Sergeant, Polaris, Minuteman and Poseidon and of anti-missile missiles.

VII. THE PRIVATE F

Tsien and the author[10] also proposed the addition of wings to a missile having the characteristics of the Private A, estimating that the range would be increased by about 50 percent with a reduced payload. We pointed out that the problems of stability and control of such an unguided missile were very complicated. The winged Private A was designated Private F (also the XF 10S1000-B),[21] and used the same Aerojet solid propellant engine. The missile was provided with fixed wings, having a span of 5 ft., stubby wings of 3 ft. span were placed at the forward end for trimming the aerodynamic forces and, at the rear, horizontal stabilizers and a vertical fin (Figure 8). The same Private A booster rockets were used. A new launcher was constructed with two rails, in order to clear the wings and tail surfaces. Design details can be found in Reference 27.

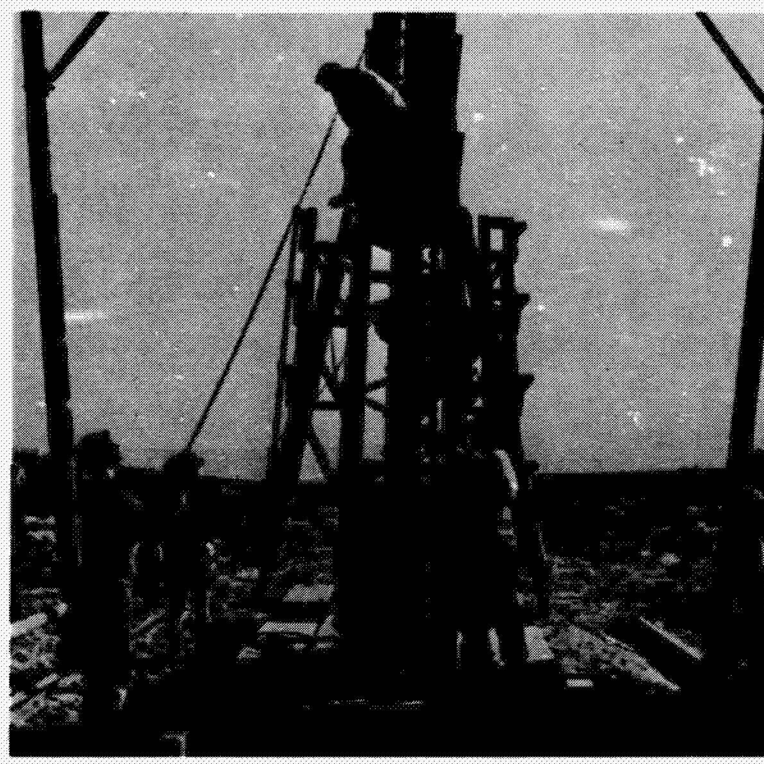

Fig. 5
View of the PRIVATE A Launcher

Firing tests were made at Hueco Range, Fort Bliss, Texas, between April 1-13, 1945. The tests began on April Fool's Day and turned out to be quite appropriate to the occasion. All of the Private F rounds, though successfully launched, went into a tail spin after a short flight (Figure 9). A striking corkscrew smoke trail was drawn in the sky by the rocket jet. Engineers concluded after a post mortem that better performance might have been obtained if the missile had been constructed with greater precision and if the lifting surfaces had been more readily adjustable.[28,29] In calmer times, after the war, when the use of funds is more carefully scrutinized, programs such as the Private F would have begun only after more theoretical studies of such a complex device had been made, and more care would have been taken in its construction.

While tests of the Private F were underway at Fort Bliss, Texas, we visited the nearby missile test range being prepared for the Ordnance Department at White Sands, New Mexico. Here, facilities were built for the tests of the WAC Corporal. These tests, in September, inaugurated the White Sands Proving Ground, then under the command of Col. H. R. Turner.

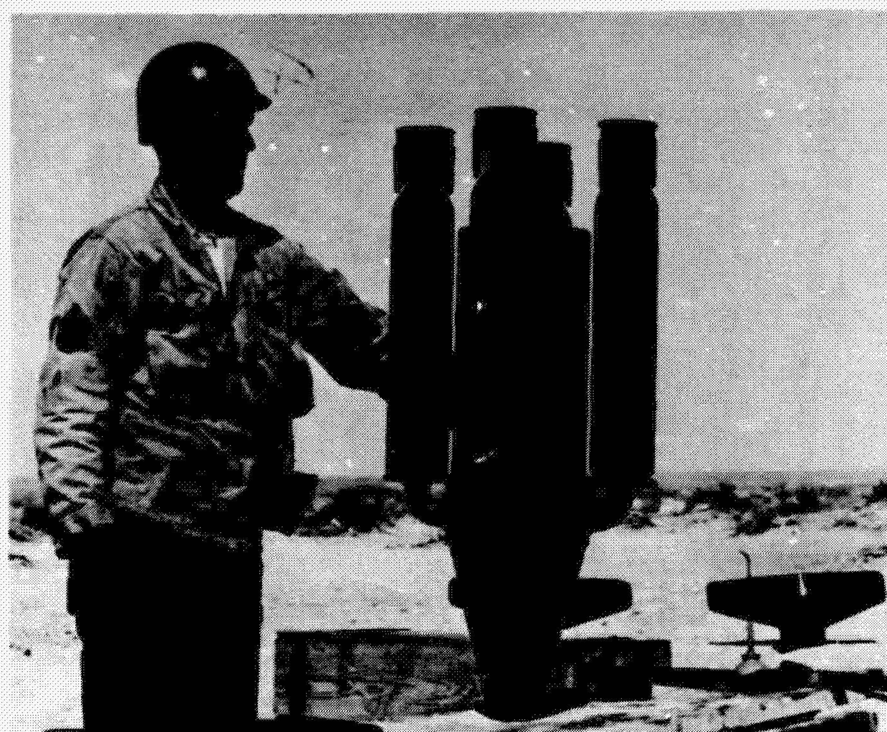

Fig. 6
Booster-Rocket Cluster for Launching the PRIVATE A Missile

VIII. THE WAC CORPORAL

The third long-range missile that Tsien and I considered[10] was to be propelled by a pressure-fed storable-liquid-propellant rocket engine of the type already developed at JPL. Our proposal contained the basic design ideas that were used in the WAC Corporal sounding rocket. Since a guidance and control system for missiles was unavailable in 1943, we proposed that a liquid-propellant missile be boosted out of a launcher by an unrestricted burning solid-propellant rocket. If launched at sufficient speed, tail fins would provide the necessary restoring force when the missile was disturbed into yaw by a cross-wind.

I have mentioned my brainstorm over the Atlantic in December 1944 that led me to obtain from the Ordnance Department authorization to design and construct a sounding rocket. It is appropriate here to review briefly the historical background of sounding rockets.[1,30] The possibility of employing rocket propulsion for lifting a vehicle to great heights was realized at the beginning of this century. Robert H. Goddard first gave serious consideration to this possibility in about 1914. At first he studied the

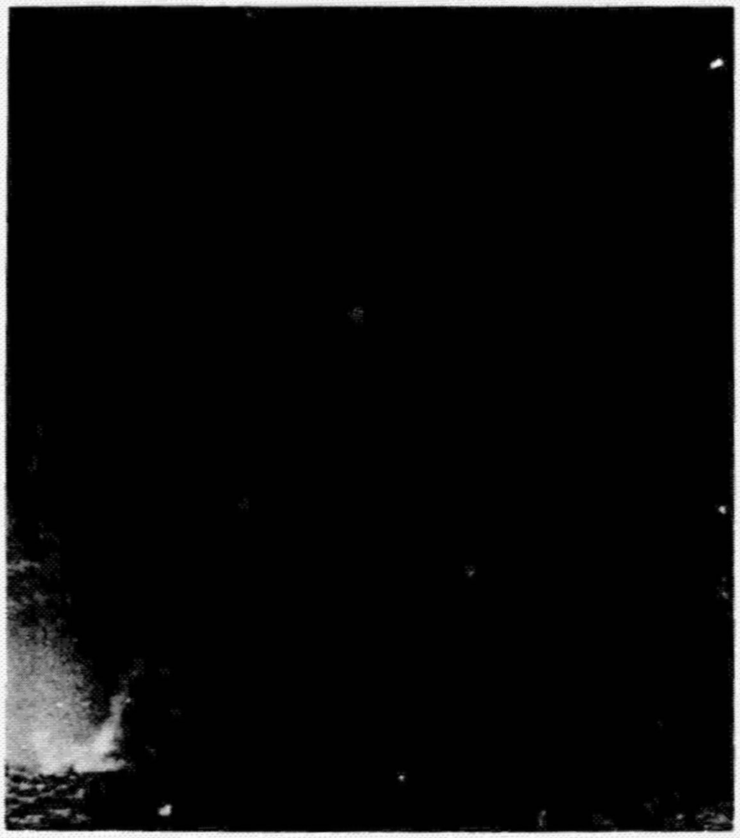

Fig. 7
View of the Smoke Trail of the PRIVATE A In Flight

feasibility of using constant-volume-process, short-duration smokeless powder rocket engines.[31,32] A more rigorous analysis of the flight performance of a rocket propelled by successive impulses was made by Tsien and the author in 1939.[19] A historical summary of sounding rockets is contained in a book recently released by NASA,[33] though it should be used with caution by historians.

Black powder rockets were capable of reaching several thousand feet before the 20th century, and balloons in the 1930s could reach altitutes of about 100,000 feet. A successful sounding rocket, therefore, had to surpass the altitudes achieved by balloons. Furthermore, to be useful, it had to be designed to minimize costs of production and of servicing and maintenance. In the 1920s Goddard had decided that a liquid-propellant rocket engine offered better possibilities for constructing such a sounding rocket, and he obtained limited financial support for developing one from the Smithsonian Institution.[34] The Daniel Guggenheim Fund for the Promotion of Aeronautics, upon the urging of Charles A. Lindbergh, began to support this work in the 1930s at the station Goddard established near

Fig. 8
View of the PRIVATE F in Launcher

Roswell, New Mexico.[34] In 1936, Goddard published a very general report on the progress of his work at Roswell.[35] In 1936 our group at Caltech concluded that Goddard had not succeeded in constructing a successful sounding rocket because he had underestimated the difficulties involved--the day of the isolated inventor of complex devices was over.[1] Even so, success for anyone in the 1920s and 1930s was not likely because of the state of rocket technology--there were no high-thrust, short-duration booster rocket engines, and no suitable guidance systems. Goddard's LOX-gasoline rocket engines, moreover, did not provide a high enough specific impulse for the task.

Similar difficulties confronted experimenters in Germany and in the Soviet Union, where a group headed by M. K. Tikhonravov first launched a liquid-propellant "Rocket 09" in vertical flight on August 17, 1933.[36] In Germany, the V-2 (A-4) ballistic missile was launched in the early 1940s in vertical flight. Though not designed as a sounding rocket, it was so used for a period in the USA beginning in April 1946.[33]

But the situation in 1944 differed radically from the one that faced Goddard ten years earlier. Solid-propellant rocket engines for boosters could be taken from wartime armament rockets and used to circumvent the necessity of a guidance system within a

Fig. 9
View of the PRIVATE F in Flight

sounding rocket. Both solid- and storable-liquid-propellant rocket engines with a thrust of sufficient magnitude and duration, and with adequate specific impulse, had been developed at JPL. Then, the Army Ordnance Department requested that JPL study my proposal for a sounding rocket. It was quickly completed and submitted on January 16, 1945 under the title "Considerations of the Feasibility of Developing a 100,000 ft. Altitude Rocket (The WAC Corporal)".[20] The WAC was to be capable of carrying an instrument payload of 25 lb., that would be lowered to the ground by parachute.

We considered the advantages of using various types of rocket engines to propel the WAC, in particular, (a) a high-thrust, short-duration ballistite engine used in armament rockets, (b) a long-duration asphalt-base GALCIT 61-C solid-propellant engine of the type used in the Private A and Private F, and (c) a nitric acid-aniline liquid-propellant engine with a cooled motor and a gas-pressure propellant supply system. Armament rocket engines were ruled out because the use of a single one as the main engine would have produced excessive acceleration of the WAC, which was not desirable from the point of view of any instruments onboard, the mechanical design, and the high drag resulting from high flight speeds in the dense lower levels of the atmosphere. The second alternative, the GALCIT 61-C solid-propellant engine, was eliminated because its weight was excessive. For the WAC to reach an altitude in excess of 100,000 ft., it was estimated that an overall impulse-weight ratio of at least 95 sec. was necessary, and not more than around

77 sec. could be obtained with the available GALCIT 61-C engine. We decided that the most feasible engine to meet WAC objectives would be the nitric acid-aniline engine. The motor to be used was a modified version of one designed by Aerojet to deliver 1,500-lb. thrust for about 45 sec.

The next problem studied was stability of the WAC in vertical flight. Given some small disturbance, gravity would cause the trajectory of a missile in vertical flight to depart more and more from the vertical. Two methods existed to assure vertical flight. The first and most direct method involved using a gyro-stabilization system together with movable aerodynamic surfaces. For the relatively small dimensions of a sounding rocket, however, the weight of such a system with its gyroscopes, servo mechanisms and other auxiliary equipment at the time was so high as to make it a rather dubious method of solving the problem. The second approach involved launching the WAC at a sufficiently high speed so that deviation from the vertical was not of any great importance. This speed could be accomplished by using a second rocket to boost the WAC quickly to a velocity of about 400 ft. per sec. before it left a launching tower. It was estimated that the WAC needed to be guided in a tower for around 60 ft. and that launching acceleration should not exceed about 50 g.

The Ordnance Department accepted these recommendations, and design of the WAC with supporting equipment began immediately. The WAC, as finally constructed and tested (Figures 10 and 11), had the following specifications:[37–40]

Overall length: 194 in.
Maximum diameter of body: 12.2 in.
Three tail fins of 24 in. half span
Gross weight: 665 lb.
Empty weight: 297 lb.
Red fuming nitric acid: 286 lb.
Aniline-furfuryl alcohol mixture: 114 lb.
Air at 1900 psi.: 19lb.
Motor thrust: 1,500 lb.
Thrust duration: 45 sec.
Impulse-weight ratio: 102 sec.

The vehicle was assembled by the Douglas Aircraft Co., Santa Monica, California, from components supplied by JPL's ORDCIT Project.

The WAC sounding rocket was boosted from the launcher by means of a modified ballistite solid propellant rocket engine from an armament projectile called the Tiny Tim (Figure 12), which had the following specifications:[37,40]

Overall length: 96 in.
Maximum diameter of body: 11.75 in.
Three Tail fins of 26 in. half span

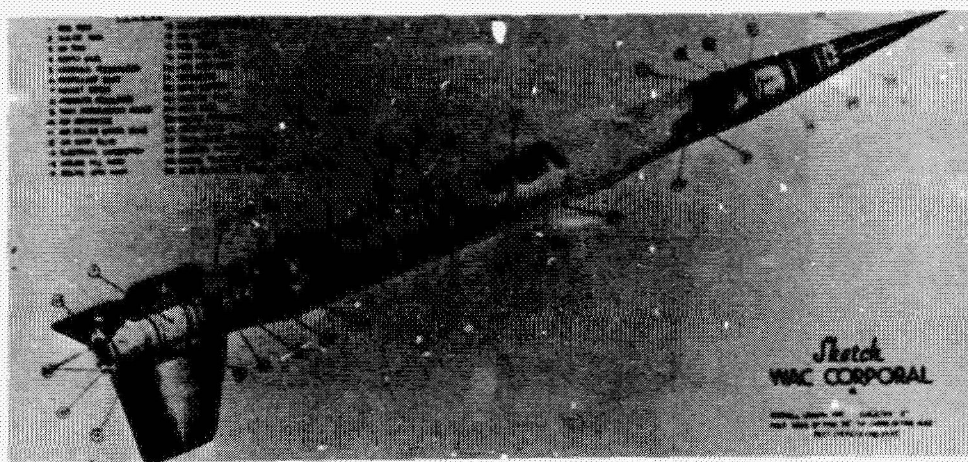

Fig. 10
Sketch of the WAC CORPORAL

Gross weight: 759 lb.

Weight of propellant: 149 lb.

Average thrust (sea level): 50,000 lb.

Nominal duration of thrust: 0.6 sec.

Impulse-weight ratio: 40 sec.

The launcher at White Sands Proving Ground consisted of a 77 ft. triangular structural steel tower, 6 feet on a side, resting on a tripol 25 ft. high with a 26 ft. base giving an overall height of 102 ft.[37,40] (Figure 13). The tower contained three launching rails set 120° apart to guide the WAC and its booster. The effective length of the rails was 82 ft. Details of the design of the launcher are given in Reference 40. A control house was constructed by the Ordnance Department 465 ft. from the launcher (Figure 13).

To check the flight characteristics, tests were made with a 1/5 scale model, called the Baby WAC. It was launched from a scaled-down launching tower at Camp Irwin, California, beginning July 4, 1945.[41] One of the interesting aspects of these tests was the verification of the suitability of employing three instead of the traditional four tail fins. For some reason, aeriel bombs and early rockets were equipped with four fins. Stewart, to save weight, proposed we use three fins. An Ordnance "expert" told us the WAC would then be unstable in flight. When Stewart pointed out that arrows for ages had three fins and had performed very nicely, he was still doubtful. The tests of the Baby WAC settled the arguments; the model behaved very well, reaching an altitude of around 3,000 ft.

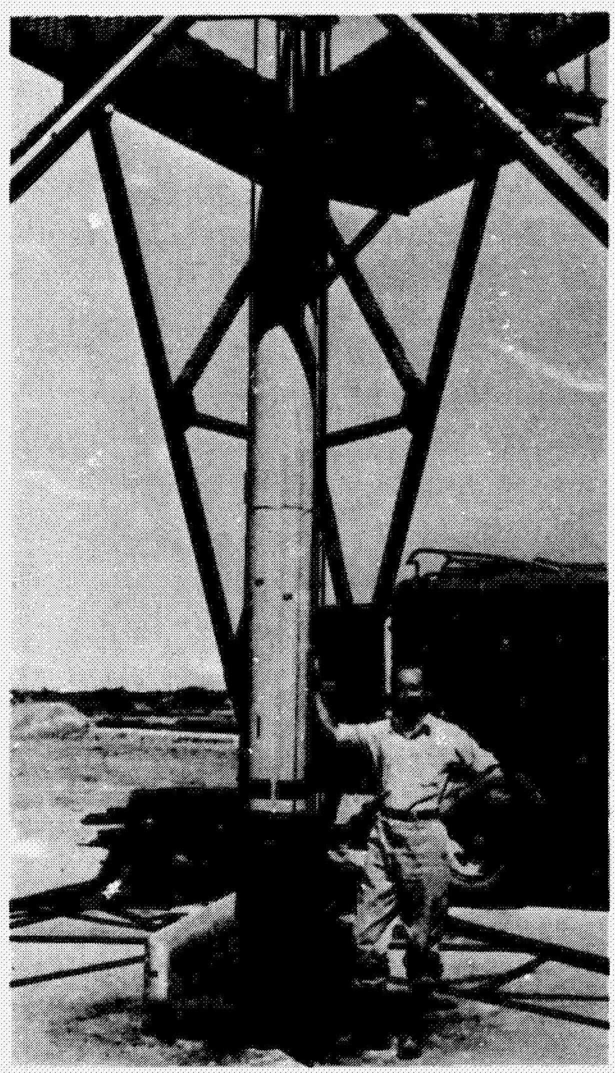

Fig. 11
View of the WAC CORPORAL With the Author

Since the WAC was expected to be used as a meteorological sounding rocket in locations that would be near populated areas, we decided to provide a 10-ft. parachute in the nose of the WAC to lower it to the ground at a velocity of around 70 ft. per sec.[37,42,43] The parachute, to be released at the zenith of WAC's vertical flight, was attached to the top of the propellant tanks and housed in the nose cone. The nose cone was attached to the WAC by means of three explosive pins inserted through the skirt of the nose cone into lugs welded on the tank head. The skirt was seated on a r bber ring

Fig. 12
View of the WAC CORPORAL Booster Rocket

Fig. 13
View of the WAC CORPORAL Launcher, Control House and Weather Tower, September 1945

seal-strip so that at launching atmospheric pressure was sealed in the nose and provided a force to push the nose away at the zenith of flight, where the outside pressure was practically zero.

Two schemes were to be tried to fire the explosive pins at zenith. The first used a gyroscope, the frame of which when the WAC turned through 90° was to close an electric circuit to the pins. The second scheme used a mechanical timing device to close the circuit at the predicted time of flight to zenith.[37] The Signal Corps provided radio sonde equipment with its own parachute to be installed in the nose cone, to be released at the same time as the parachute of the WAC.[37] It also provided weather information, including data obtained from balloons rising up to about 100,000 ft.

The WAC was tested at the White Sands Proving Ground in New Mexico during September 26 to October 25, 1945, just nine months after I proposed the sounding rocket to Trichel in Washington, D.C. Details of the test program can be found in References 37 to 44. The Ordnance Department provided a C-47 Douglas aircraft to transport personnel and equipment between Los Angeles and White Sands—it was, of course, called the ORDCIT Airline. A detour was made on one flight so we could see the blast area near Alamogordo, New Mexico, caused by the explosion of the first atom bomb. It was a very disturbing sight, especially for us who were involved in the development of long-range rocket missiles.

In 1936, I had placed on my office wall at Caltech a chart showing the component parts required for a successful sounding rocket. The dream had now become a reality, with an engineer in charge of each of those components. Key members of my WAC team were: M. M. Mills (Booster), P.J. Meeks (Sounding Rocket), W.A. Sandberg and W.B. Barry (Launcher and WAC Nose), S. J. Goldberg (WAC Field Tests), H. J. Stewart (External Ballistics) and G. Emmerson (Photography).

A group photograph of most of the ORDCIT Project personnel who participated in the test program at White Sands is shown in Figure 14, and the organization chart of the groups participating in the WAC Corporal program in Figure 15. The large number of people involved in this program indicates why the dreams of individuals and small groups of rocket enthusiasts in the 1920s and 1930s to design, construct, and test a high-altitude sounding rocket had little chance of success. Fortunately, most pioneers do not foresee all of the practical implications of their dreams.

The test program proceeded step by step until we were confident that basic components were satisfactory. First, four rounds of the weight-adjusted Tiny Tim booster alone were fired to check the booster, launcher and firing controls, and to give practice to radar and camera crews. Next, two dummy rounds of the WAC constructed of steel tubing filled with concrete were launched. These were followed by two WAC rounds with a partial charge of propellant to check behavior of the liquid-propellant rocket engine, the separation of the booster from the WAC and the operation of the nose cone release mechanism. Up to this point, all systems operated satisfactorily except for the nose cone release mechanism, which failed both times. The partial charge WAC reached an altitude of about 28,000 ft., though difficulties were encountered in tracking it with radar.[37,44] Radar tracking

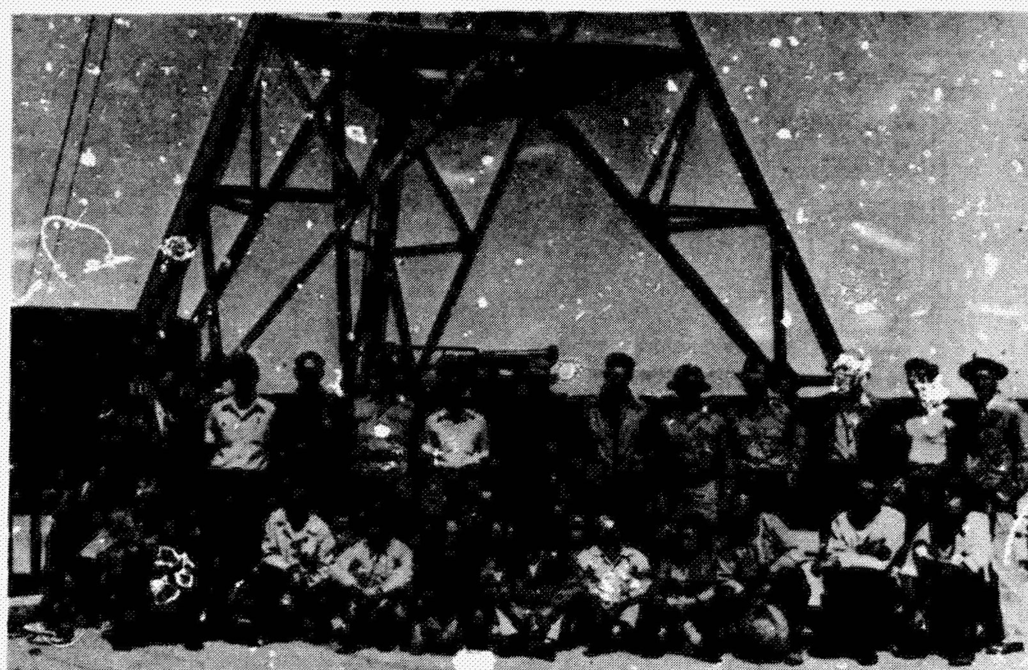

Fig. 14
Group Photograph of ORDCIT Project Personnel Who Participated in the WAC CORPORAL Test Program at White Sands Proving Ground, New Mexico Between 24 September and 25 October 1945

at this time was still in a rudimentary state of development. The radar group from the Ballistic Research Laboratory at Aberdeen Proving Ground, headed by L.A. Delsasso, dealt with these difficulties.

October 11, 1945, became our great day for the first flight of the WAC (Round 5) fully charged with propellant. We craned our necks to watch the WAC's smoke trail until the engine stopped at around 80,000 ft. On the basis of radar tracking data, it was estimated that the maximum altitude reached was between 230,000 and 240,000 ft. The total time of flight was about 450 sec. or 7.5 minutes. The velocity of the WAC at the end of burning was about 3100 ft. per sec. The impact point of the 1st round was about 3,500 ft. from the launcher, which meant that the WAC had maintained a very satisfactory vertical path. Success!

I was the sole member of the original GALCIT Rocket Research Group of 1936 to experience the culmination of its hopes after the many vicissitudes in rocket development over the ensuing period of 10 years. It is difficult to describe my feelings as I watched the sounding rocket soar upward. One can think of many things in a few minutes. One of my thoughts was that I could now turn my mind to other goals in a world full of both fascinating technological possibilities and of desperate social problems. In the

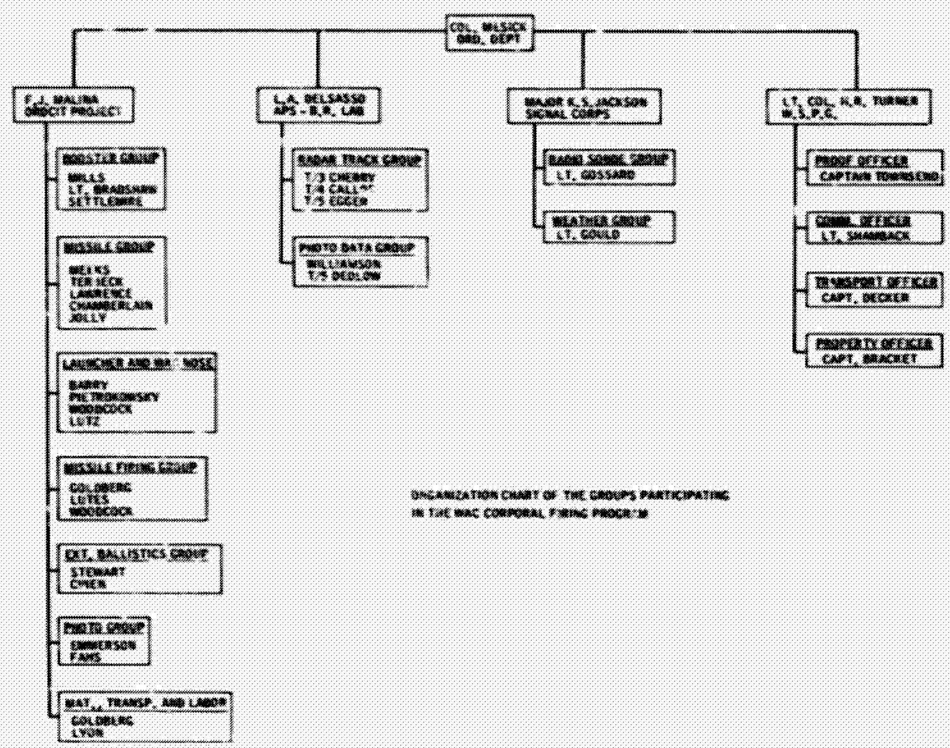

Fig. 15
Organization Chart of the Groups Participating in the WAC CORPORAL
Test Program at White Sands Proving Ground, New Mexico
Between 26 September and 25 October 1945

astronautical fraternity, the tradition of lighting up a cigar had not as yet begun. We contented ourselves by letting out whoops of joy, shaking hands and patting each other on the back. Our celebration was of short duration. We quickly returned to work to prepare for the launching of the next round of the WAC the next day!

Six charged rounds were fired during this 1945 program. In round 7, the nose cone release mechanism functioned prematurely at about 90,000 ft. and in round 8 the nose cone was released prematurely shortly after the WAC left the launcher but it continued in vertical flight. The parachute did not lower the WAC to the ground successfully in any of these flights, for it either failed to release, released prematurely, or tore off during descent. This did not surprise us, as there was very little experience on the behavior of parachutes opened at high altitudes. When the parachute failed the first time, instead of seeking cover, many of us remained standing in the impact area because Homer Stewart assured us that the probability of being struck was extremely small. Even so, we were startled to see one impact take place about 200 yards from where we were standing.

When the center of gravity of the WAC was too far forward it went into a flat spin during its fall to the ground and, as a result, it struck the ground at greatly reduced speed. Round 6, in remarkably good condition after impact, is shown in Figure 16.

Fig. 16
View of Round 6 of the WAC CORPORAL After Impact on the Ground

The last flight, round 10, was made at night. A view of the jet trail above the launcher is shown in Figure 17. The plot of radar data obtained for this flight is shown in Figure 18. Radar tracking gave a minimum of data to permit the altitude to be calculated. On most rounds it failed completely. The fact that radar now can be used to map the surface of a distant planet seems incredible.

The test of the WAC Corporal showed that design features we chose for a practical sounding rocket of reasonable cost were correct. The use of a booster rocket and an adequate launching tower circumvented the need of a guidance system. The use of a storable liquid propellant engine simplified launching procedures compared to the use of LOX engines.

is a tradition at JPL to be conservative and unsensational in making proposals when dealing with problems involving many unknowns. Thus, we set the altitude to be attained at above 100,000 ft. Since no liquid-propellant engine sounding rocket before had reached more than a few thousand feet, that seemed quite ambitious. The fact that the WAC doubled our first theoretical altitude estimates was primarily due to a reduction of the empty weight and the increased amount of propellant carried.

The recommendations made as a result of the tests included:

1. Shifting the compressed air tank from the bottom to the top of the tank assembly in order to shift the center of gravity forward.
2. Suggestions for further reducing the empty weight of the vehicle.
3. Designing of a reliable nose cone release mechanism and of a stronger attachment of the parachute to the vehicle.

Fig. 17
View of the Night Flight of the WAC CORPORAL on 25 October 1945

4. Provision of a radar beacon on the vehicle to facilitate radar tracking.
5. Design of a booster rocket with an improved impulse-to-weight ratio.

When tests of the WAC concluded in October, we began studies for another sounding rocket given the designation Sergeant. It was to be about the same size as the WAC but with a new cooled or uncooled motor, perhaps a ducted rocket motor, and a gas-generation-propellant supply system. This program was not pursued, and Sergeant later became the name of a solid-propellant guided missile designed at JPL.

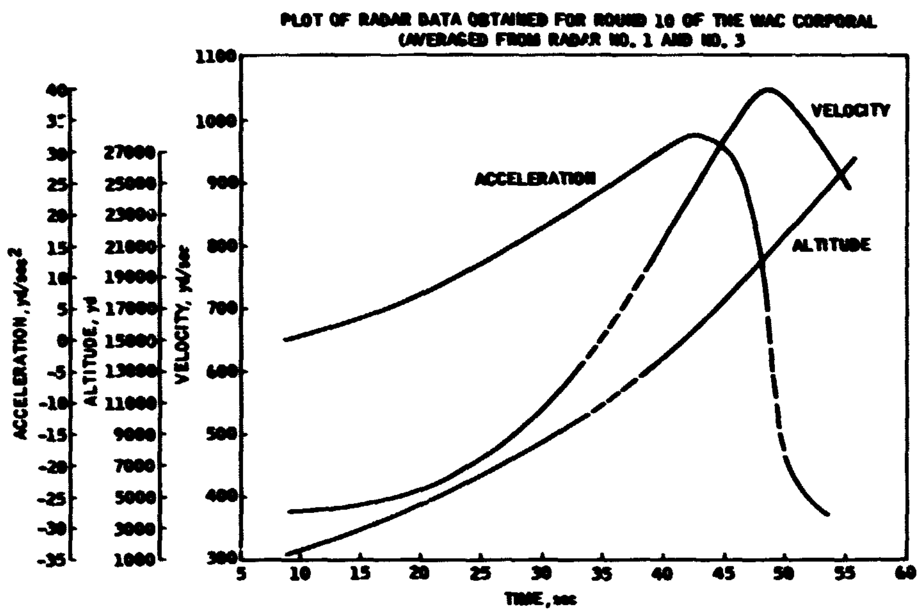

Fig. 18
Plot of Radar Data Obtained From Round 10 or the
WAC CORPORAL Fully Charted With Propellant

On November 9, 1945, at Aberdeen, Maryland, representatives of the Ordnance Department and the Signal Corps met with JPL personnel to review the results of the WAC tests.[46] It was decided that another five rounds of the WAC should be assembled and used for testing an improved parachute and parachute release system, a remitter beacon in the nose for radar tracking, and a data telemetering system. Various tests were conducted in connection with this program at White Sands Proving Ground between May 7-29, 1946.[45,46]

While these tests were underway, we first met members of the German V-2 development team who had been brought to the U.S.A. to be incorporated into the Ordnance Department's long-range missile program. Wernher von Braun acted as spokesman for the group. By this time we were quite well acquainted with the V-2 missile. Two complete ones were received at JPL in June 1945. Their arrival on two railroad flat cars caused more excitement among the people of Pasadena than a whale similarly transported some time before.

In March 1946, plans were initiated for the design and construction of the improved WAC Corporal B sounding rocket, with Meeks as Project Coordinator. The vehicle incorporated the recommendations resulting from the tests of October 1945, and later, those of May 1946, as well as a lighter weight redesigned engine and propellant tanks to increase the propellant-to-gross weight of the first design. A report on the tests of the WAC B at White Sands Proving Ground in December 1946 and in February - March 1947 can be found in Reference 47.

The results and know-how obtained with the WAC Corporal were incorporated in its successor, the Aerobee, designed and constructed by Aerojet and assembled by the Douglas Aircraft Co. That project, sponsored by the Navy Bureau of Ordnance, was carried out under the technical direction of the Applied Physics Laboratory of Johns Hopkins University, supervised by James A. Van Allen. The contract to Aerojet was awarded on May 17, 1946, and the first full-scale Aerobee was launched at White Sands on November 24, 1947.[33,47] Since 1948, numerous variations of the basic WAC design have been constructed in the USA and in other countries for use in high-altitude research.[33]

IX. THE CORPORALS

A major objective of the ORDCIT Project, as described in Section III, was the development of a remotely controlled missile to carry an explosive load of 1000 lb. for a distance of up to 150 miles, with a dispersion not in excess of 2 percent and at a velocity sufficient to afford protection from fighter aircraft. On August 14, 1944, Tsien outlined a program for an experimental missile (with the designation XF36 L 20,000) that had the following tentative specifications:[48]

Gross weight: 5 tons
Diameter: 36 in.
Rocket thrust: 20,000 lb.
Thrust duration: 60 sec.
Sp. propellant cons: 0.005 sec.
Stabilization: fins
Range: 30 to 40 miles

At this time, only a storable-liquid-propellant engine of the type developed by JPL could meet these specifications; the thrust required was much higher than any motor constructed in the U.S.A. up to that time. The largest uncooled motor that had been tested at JPL delivered about 5,000 lb. thrust.

We also faced a requirement to launch a large rocket vertically without a booster rocket and a guiding launcher. I do not believe that we knew in early 1944 that the V-2 was launched in this way. There was considerable scepticism voiced over the possibility of keeping a large missile in a vertical position solely by means of tail fins and control surfaces as it slowly lifted off the ground. On the other hand, it was not feasible to boost a large, lightly constructed vehicle at a high velocity.

Detailed analysis of the various components and of the flight characteristics of the missile began immediately. The design and testing of the 20,000-lb.-thrust nitric acid-aniline type engine was initiated under the supervision of Howard Seifert. We decided to develop two engines simultaneously: an engine with a gas-pressure propellant supply system, with which much experience had already been gained, for installation in a missile designated the Corporal E, and an engine with a turbine-driven-pump propellant supply system engine (turborocket) for installation in the Corporal F. The development of a turborocket engine, already underway for some time by N. Van de Berg, was speeded up.[2] Facilities for testing the complete Corporal engines were constructed at the Muroc Flight Test Base, California, of the Air Technical Service Command. They were completed in June 1945 and operated under the direction of W. B. Powell.[12]

When Dunn became Assistant Director in 1944, he devoted much of his effort to the Corporal program. In the summer of 1945, Summerfield returned from Aerojet and became coordinator of the program.[45] Information on work carried out by the end of 1946 on the aerodynamics and mechanical design of the Corporals can be found in the archives of JPL.[48-64] Fabrication of components of the missiles was sub-contracted to machine shops in the Southern California area. The construction of components became the main bottleneck in the program because the ORDCIT Project at this time could not compete with priorities assigned to other production orders of the Armed Forces for the final year of war in the Pacific Theater of Operations.[12]

The problems of remotely guiding and controlling a missile were entirely new to JPL and, furthermore, no work had been carried out on aircraft autopilot systems at the Caltech Guggenheim Aeronautical Laboratory. Upon the suggestion of Skinner, consideration was given to making contractual arrangements on Corporal guidance development with either C. Stark Draper's group at the Massachusetts Institute of Technology (M.I.T.) or the Sperry Gyroscope Co.[12 +] Meetings between von Kármán and Trichel on July 29, 1944, and Martel and the author on August 24 with Sperry personnel, led to a contract between JPL and Sperry for the cooperative development of the Corporal guidance system.[12] I especially enjoyed making the acquaintance of Gifford E. White of Sperry, who, with Pickering, laid the basis for the guidance system.[66] C. B. Millikan, who had wide experience in aerodynamics, devoted much time to getting this program underway. Primarily through his efforts, Pickering joined the staff of JPL in August 1944 to establish the Remote Control Section, with Frank Lehan as his principal assistant. Information on the work carried out under this Section up to the end of 1946 can be found in the archives of JP.[45,66]

I believe memoirs by Dunn, Pickering, and Summerfield on the Corporal programs would be most valuable, for they were responsible for its development after 1946.[++] The

[+] See C. Stark Draper, "The Evolution of Aerospace Guidance Technology, 1935-1951: A Memoir," in this volume - Ed.

[++] See William H. Pickering with James H. Wilson, "Countdown to Space Exploration: A Memoir of the Jet Propulsion Laboratory, 1944-1958," in this volume - Ed.

Corporal was successfully fired at White Sands on May 22, 1947 (cf. Figure 19), becoming a tactical weapon of the U. S. Army in April 1954.

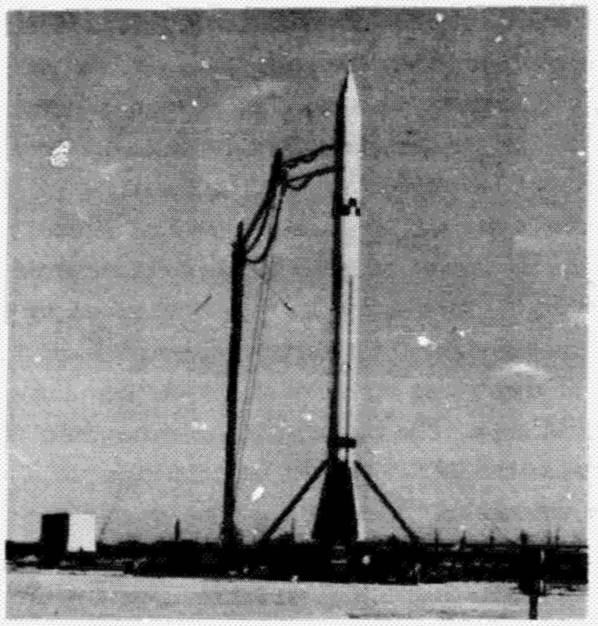

Fig. 19
The CORPORAL Guided Missile

X. SOLID-PROPELLANT RESEARCH AND APPLICATIONS

Sponsorship of solid-propellant research was taken over by the ORDCIT Project from the Air Force Materiel Command on July 1, 1944.[2] By this time, JPL had made the following fundamental contributions to the design and construction of long-duration solid-propellant engines:[2]

(a) Theory

1. Von Kármán-Malina theory of constant-thrust long-duration engines (1940)

(b) Propellant development

1. Parsons' break-away from ballistite with amine black powder (1940)
2. Parsons' introduction of perchlorates as an oxidizer (1942).
3. Parsons' introduction of asphalt as a fuel-binder with perchlorates; the invention of a castable case-bonded composite propellant charge (1942).

(c) Engine component design

Parsons' design of a restricted-burning (case-bounded) propellant charge with amine black powder (1940).

2. Malina-Mills design of a safety pressure relief valve (1942).
3. Mills' review of various types of burning surfaces of a charge and theoretical confirmation that the surface of a cigarette-type burning charge was stable (1943).

After the successful JATO development with the asphalt-perchlorate propellant in 1942, Mills sought a fuel-binder for the perchlorate superior to asphalt. In 1944, Charles Bartley joined Mills' group, and in 1945 introduced as a replacement for asphalt a castable elastomeric material, polysulfide rubber, produced by the Thiokol Chemical Corporation. A report on the development of this propellant can be found in Reference 67. The polysulfide rubber compared to asphalt produced a propellant much better both as regards storage temperature limits and hardness at high atmospheric temperatures. The latter property was especially important in the design of high-thrust engines requiring a charge with an internal-burning surface rather than a cigarette-burning surface.[68] Since at this time only Aerojet in the U.S.A. was producing composite solid-propellant engines, I drew the company's attention to the asphalt replacement, but it was already interested in a similar material made by the General Tire and Rubber Co. I believe it was at the urging of the Ordnance Department that the Thiokol Chemical Corp. entered the field of composite solid propellants with the new fuel-binder found at JPL.

After obtaining the experience with the composite solid-propellant missiles Privates A and F, studies began at JPL in 1946 on larger missiles using, in particular, the polysulfide rubber-perchlorate type of propellant. The results of these studies[69] led eventually to the design of the tactical guided missile, Sergeant.

The Laboratory followed closely developments with other types of solid propellants, especially ballistite, used in high-thrust short-duration engines suitable for boosters. Available engines were modified to meet special requirements for boosting the Privates and the WAC Corporals.

Considerable research was also conducted by the Solid Propellant Rocket Section under Bartley, and the Propellant Section under N. Kaplan, and later under S. A. Johnston, on gas generation systems to replace stored gas for feeding liquid propellants to rocket motors. Our optimism that such a system could be developed quickly proved to be unfounded (See Section VIII).

XI. APPLICATION OF ROCKET PROPULSION FOR EXTRATERRESTRIAL SPACE EXPLORATION

I have described the background of the initiation of rocket research at Caltech in my first memoir on the GALCIT Rocket Research Project, 1936-38.+ Space travel, which was the goal of this Project, was not stressed after we realized that existing rocket technology was insufficient to reach this goal. It is true that journalists published stories interpreting our studies of sounding rocket performance and preliminary rocket engine experiments as heralding a planned landing on the Moon by Caltech. It was not until after work on the Corporal was initiated in early 1945 that studies resumed that had been put aside in 1938 (See Section V).

The WAC could be considered as a two-step rocket vehicle. Summerfield and I began, I believe, in the summer of 1945 a more detailed analysis of such vehicles, with a re-evaluation of the feasibility of a rocket payload being launched at suffucient velocity to escape the gravitational field of the Earth. Our analysis was based on the state of rocket technology at that time, and included a discussion of the possible use of a nuclear energy rocket engine.[70] The analysis led to the Malina-Summerfield Criterion for step-rockets, which states that the optimum step-rocket will be one in which the ratio of the mass of payload for each step to the mass of the step propelling the payload is the same (the payload for step one is the mass of all succeeding propulsion steps plus the mass of the final useful payload).

We calculated, as an example, a step-rocket to launch to escape velocity a useful payload consisting of an instrument for measuring cosmic ray intensity with a radio beacon transmitter for sending the data back to Earth. Obviously, if a useful payload could be launched to escape velocity, it could also be placed in orbit around the Earth. JPL's first satellite, Explorer 1, on January 31, 1958, carried a cosmic ray instrument, and the payload weight was about the same as we had chosen. On January 3, 1946, in Washington, D.C., I presented the results of our study, as well as the high points of achievements at JPL, to the War Equipment Board of the Army, headed by General Joseph W. Stilwell. As I recall, the Board made little comment on the implications of the possibility of launching a man-made object away from the Earth. Stilwell observed in his diary in regard to his assignment to the Board: "I am eminently suited to do something else and would as lief sit on a tack."[71]

+Frank J. Malina, "On the GALCIT Rocket Research Project, 1936-1938," First Steps Toward Space: Proceedings of the First and Second History Symposia of the International Academy of Astronautics, Smithsonian Annals of Flight, No. 10, Washington, D.C., 1974; also in Russian in From the History of Rockets and Astronautics (Moscow: Publishing House Nauka, 1970).

We had made conservative assumptions in our "escape" analysis, especially as regards propellant specific impulse and structural weights of vehicle components. We estimated that a 5-step rocket to launch a 10-lb. payload to escape velocity would have to weigh 3,000,000 lbs. for the nitric acid-aniline propellant combination, and that 450,000 lbs. would be required for oxygen and ethanol. It was difficult for almost anyone in 1946 to imagine meeting the engineering problems and cost of constructing such rockets.

The analysis we made was correct, as J. E. Froehlich pointed out in 1959.[72] However, between 1946 and 1959 improvements in engines and structural design permitted the gross weight required to launch a payload to escape velocity to be reduced by a factor of over 400. This is certainly an amazing demonstration of the possibilities of technological research and development when there is a will to support them--for good or evil purposes.

On July 7, 1946, I returned to London on a second mission in Europe for the Army Ordnance Department. Assigned to the office of Colonel Reed, Assistant Military Attache, I was asked to report on matters related to science and technology as well as rocket propulsion and missile design. I remained in Europe until December 1946. During this time I visited von Kármán several times and we discussed aspects of the post-war situation, especially as they affected our plans for the future.

I discussed our "escape" study at a meeting of the British Interplanetary Society (BIS) in London, and presented the paper formally at the Sixth International Congress for Applied Mechanics in Paris.[70] Members of the BIS who attended the meeting were not very happy when I said that at this time one could land a man on the Moon, provided he was sent up in two halves in separate rockets, without the offer of a return trip to Earth.

One result of this study was Summerfield's suggestion that a program be initiated to launch a two-step rocket vehicle consisting of the WAC Corporal boosted by the V-2. Initiation of this program at JPL was authorized by the Ordnance Department in October 1946, and the vehicle was designated Bumper WAC. A photograph of the rocket is shown in Figure 20. It was successfully launched at White Sands Proving Ground on February 24, 1949 and the WAC reached an altitude of 244 miles.[73] Thus the WAC became the first recorded man-made object to enter extra-terrestrial space, and the "space age" could be said to have been opened in the U.S.A. in 1949. On July 24, 1950, a Bumper WAC became the first missile launched from Cape Canaveral.

While Summerfield and I were concluding our "escape" study, the Navy Bureau of Aeronautics on 12 December 1945 made a contract with JPL for studies of a rocket vehicle for launching an Earth satellite. The work of the Navy and of JPL on this program can be

Fig. 20
The BUMPER-WAC Rocket Vehicle

found in a detailed historical paper by R. Cargill Hall in this volume. Unfortunately, for the reasons he puts forward, the Navy dropped the program in 1947.

A summary of the basic aspects of the physics of space flight as understood at JPL in 1946 can be found in a paper by Seifert, Mills and Summerfield.[75] A Guided Missile and Upper Atmosphere Symposium was held at JPL between March 13-16, 1946, in which experts from all parts of the USA participated.[76]

XII. CONCLUDING REMARKS

There are many areas of research conducted under the ORDCIT Project that I have not discussed in detail, for example, work on materials, chemistry of propellants, ramjet design, telemetering of data from missiles in flight and remote control of missiles. The main reason is that my role in these domains was mainly of an administrative character and, therefore, those that led the actual work would best be able to shed light on this work.

The preparation of my three memoirs on the origins and work the JPL between 1936-46 has heightened my appreciation of the difficulties confronting historians of science and technology. Not only must historians understand the technical matters of a development, but they must make interpretations requiring wide historical perspective. If, in addition, these historians wish to portray the events accurately for the lay public as well as technical scholars, then their task is a most difficult one indeed—and if great care is not exercised, the truth will be replaced by myth.

APPENDIX

CONTENTS OF CALTECH'S PROPOSAL OF 28 FEBRUARY 1944
TO THE ORDNANCE DEPARTMENT (cf. Reference 12)

1. Theoretical investigations on the possible range as a function of the initial weight and the ratio between warhead and initial weight. It is especially necessary to decide whether pure projectiles or wing missiles or both types should be developed.

2. Theoretical and experimental investigations on stability and aerodynamic control. Study of tail stabilizers for projectiles and wing missiles; spinning devices for pure projectiles.

3. Development of an adequate propulsion system. Liquid rockets for indefinite duration, and solid rockets up to 45-second duration have been developed by the GALCIT Project and the Aerojet Engineering Corporation....

4. Study of the launching system; development of adequate guiding rails and auxiliary launching equipment.

5. Construction of model projectiles of moderate size (300 to 2,000 pounds) in order to obtain data on drag, stability, propulsion efficiency and dispersion for the prototype project.

6. Methods of remote control.

7. Development of adequate experimental technique for firing tests, execution of firing tests, and evaluation of results.

It is believed that the Institute could undertake the pursuit of these objectives. As far as items 1 to 5 are concerned, the Institute would undertake, with its own adequately enlarged personnel, theoretical and experimental development work and would subcontract in the Los Angeles area the design and construction of launching equipment and actual models destined for firing tests. A preliminary survey of available shop and manpower facilities in the local industry indicates that such a procedure would be feasible. As to items 6 and 7 it will be necessary that the Ordnance Department select and maintain sites for the firing tests, furnish personnel and materials for execution of the tests, and especially instrumentation and personnel from the Ballistic Research Laboratory for the ballistic measurements.

The laboratory development work should be carried out on a tract owned by the Institute adjoining the Air Corps Jet Propulsion Research Project. Ample space is available for the necessary facilities for laboratory work and ground tests on propulsion systems.

As a tentative proposal, the following items are respectfully submitted:

A. The Institute's Responsibilities

I. To furnish comprehensive reports on the following items:

a. On the possible range and bombing load of large-size rockets.

b. On stability and aerodynamics control of such rockets.

c. On characteristics of adequate propulsion systems.

d. On the characteristics of various launching systems.

II. To design and construct the necessary facilities and carry out experimental research on propellants and materials involved in the design of long-duration rockets and athodyds; to carry out ground tests on the characteristics of such devices; to carry out and/or direct and supervise wind tunnel and airplane flight tests on athodyds.

III. To establish basic engineering data for the launching devices selected for firing tests.

IV. To establish basic engineering data for the model projectiles to be used in firing tests.

V. To supervise the design and construction of model projectiles and launching equipment subcontracted to engineering and manufacturing organizations selected by the Institute.

VI. To set up a program for the firing tests and cooperate in carrying out the tests and evaluate the results based upon all proof data obtained.

VII. a. To establish the specifications and basic engineering design data for for one or more prototype units.

b. To supervise the design and construction of prototype units and pertinent launching equipment by engineering and manufacturing organizations selected by the Institute.

B. The Ordnance Department's Responsibilities

I. To furnish the necessary funds for the facilities, materials, supplies, salaries, wages, and other expenses including a fee covering the overhead involved by the general administration of the Institute.

II. To select, equip, and maintain suitable sites for firing tests.

III. To furnish personnel, materials, and supplies for execution of the firing tests including the instrumentation and personnel from the Ballistic Research Laboratory for the necessary ballistic measurements and to be responsible for all safety precautions.

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